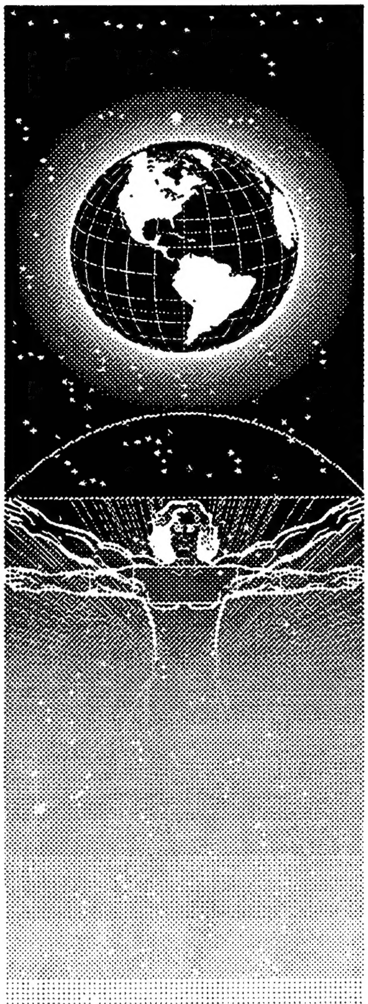
AFRL-HE-WP-TR-1998-0006



UNITED STATES AIR FORCE RESEARCH LABORATORY

REDUCING CANNON PLUG CONNECTOR PIN SELECTION TIME AND ERRORS THROUGH ENHANCED DATA PRESENTATION METHODS

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June 1998

Final Report for the Period February 1998 to March 1998

Approved for public release; distribution is unlimited.

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NOTICES

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-1998-0006

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

For [illegible] LtCol
JAY KIDNEY, Col (Sel), USAF, BSC
Deployment and Sustainment Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1998	FINAL From Feb 98 to Mar 98

4. TITLE AND SUBTITLE
Reducing Cannon Plug connector Pin Selection Time and Errors through Enhanced Data Presentation Methods

5. FUNDING NUMBERS
C-SPO900-94-D-0001
PE - 62202F
PR - 1710
TA - DO
00 - 03

6. AUTHOR(S)
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Dayton OH 45469

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-HE-WP-TR-1998-0006

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
Human Effectiveness Division
Logistics Readiness Branch
2698 G Street
Wright-Patterson AFB OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This research investigated the effects of data presentation formats on maintenance technician performance when maintenance procedures are presented on a monocular, head-mounted display (HMD). Two formats were used to present the maintenance procedure information to the technicians: 1) a format which mimicked the standard technical procedure manual format, including the textual and graphical aspects of the format; and, 2) a format which provided the same information as the first, while adding visual cues as part of the graphical portion of the technical information. United States Air Force (USAF) avionics maintenance technicians stationed at Barksdale Air Force Base, Louisiana served as subjects. Dependent measures were task completion time, task error rate, and technician self reports on the usability of the HMD. Results indicate that technicians perform tasks more quickly and commit fewer errors when using enhanced graphical data presentation methods to perform the tasks. The technician indicated that HMDs could be a useful tool in the performance of their maintenance duties.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Aircraft Maintenance; Head Mounted Display; Human-Computer Interaction; Cannon Plug	28
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

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PREFACE

This report provides results for a field study conducted at Barksdale AFB, LA. The study showed the importance of enhanced presentation of cannon plug data. The effort was accomplished as a cooperative research project between the Air Force Institute of Technology (AFIT) and the Air Force Research Laboratory, Logistics Readiness Branch (AFRL/HESR). While attaining his master's thesis, Capt. Bob Webb provided background literature reviews, data collection and analysis of the data obtained for this study. Concept development, technical direction, hardware and software development, and Technical Report writing were accomplished by the University of Dayton Research Institute (UDRI) (Contract No. SPO900-94-D-0001, DO. 0005) and AFRL/HESR.

Special thanks to the 2nd Bomb Wing at Barksdale AFB, LA for their support in this effort.

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SUMMARY

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United States Air Force (USAF) avionics maintenance technicians stationed at Barksdale Air Force Base, Louisiana served as subjects. Dependent measures were task completion time, task error rate, and technician self reports on the usability of the presentation methods and the HMD. Results indicate that technicians perform tasks more quickly and commit fewer errors when using enhanced graphical data presentation methods to perform the tasks. The technicians indicated that HMDs could be a useful tool in the performance of their maintenance duties.

INTRODUCTION

Background

Since the early 1980s the Department of Defense (DoD) and commercial industry have been moving to digitize, computerize, and automate the technical manuals used by maintenance technicians to troubleshoot, repair, and maintain aircraft systems. Computer-based maintenance aids that provide interactive system tests and access to technical information currently exist in the operational environment. Ultimately, such systems may become the primary information source for tasks that presently require the use of paper-based technical documentation. As these digitization efforts proceed, the logistics research community is investigating methods to efficiently accomplish this task while discovering means of decreasing logistics costs.

Military Maintenance Applications

In the military environment, maintenance is continually performed in less than ideal conditions. For example, technicians often work outdoors in a wide range of temperatures and weather conditions. Furthermore, specific maintenance tasks may require completion within a confined area, such as a landing gear or engine bay. In order for any maintenance aid to be a true asset, it must be usable in such conditions. Consequently, most maintenance aids are being designed as ruggedized, portable laptop computers capable of withstanding extreme environmental conditions. Improvements in hardware and software technologies have increased the viability of implementing alternatives configurations, such as wearable computers with head-mounted displays (HMDs). These wearable computers with HMDs have been shown to provide the mobility necessary to perform inspection tasks more accurately than a portable computer (Friend & Grinstead, 1992). Overall, research has shown that maintenance aids can improve technician performance in problem identification, task completion times, and reduced maintenance costs (Schroeder, Smith, Bursch, & Meisner, 1992; Friend & Grinstead, 1992; Thomas, 1995).

Logistics researchers Wright-Patterson AFB, Ohio, designed and specified the technologies necessary for an Integrated Maintenance Information System (IMIS). The IMIS proof-of-concept field test indicated that technicians commit a significantly higher number of errors when using paper-based maintenance procedures than when using electronically presented procedures. However, in both paper and electronic conditions, correct identification and selection of cannon plug pins was identified as a highly error-prone task. One of the most common error types in both the paper and electronic conditions involved reading the wrong pin on a cannon plug. Therefore, although digitizing technical manual does improve performance overall, there are still areas (such as reading cannon plug pins) that require further improvement.

Several automated maintenance aids currently exist in the military maintenance community. Maintenance Error Decision Aids (MEDA), Avionics Troubleshooting Systems (ATS), Flight Control Maintenance Diagnostic Systems (FCMDS), Aviation

Diagnostics and Maintenance (ADAM) systems, and Integrated Maintenance Information Systems (IMIS) are all examples of the computer-based aircraft maintenance aids that are beginning to appear on Air Force flightlines (Hibit and Marx, 1994; Gulick and Kell, 1993; Schroeder, Smith, Bursch, and Meisner, 1992; Le Beau, et. al., 1991; Thomas, 1995).

HMD Research in the Aircraft Maintenance Environment

In 1991, Masquelier compared the use of an HMD to a flat-screen computer during routine, intermediate-level bench top troubleshooting tasks. In this stationary position, no statistical differences were found in performance between the group that used the HMD and the group that used the flat-screen display. However, Masquelier noted that a similar study with mobility requirements might result in performance differences.

Friend and Grinstead (1992) conducted the follow-up study recommended by Masquelier. Working in a flightline maintenance environment, technicians were required to move around the airplane to conduct inspection and fault isolation tasks. As with Masquelier, aircraft maintenance technical data was presented either on an HMD or flat-screen display. The important difference between Friend's and Grinstead's (1992) and Masquelier's (1991) studies is that technicians in Friend's and Grinstead's (1992) study conducted tasks on an actual flightline, in normal flightline working conditions. In the flightline environment, which requires increased mobility, technicians using the HMD completed the task more quickly and accurately than the technicians that used the flat-screen display. Cannon plug pin tests are commonly performed in mobile flightline maintenance; therefore, due to Friend's and Grinstead's finding, this study used a HMD as the display device of choice.

HMD Advantages and Disadvantages

When compared to traditional flat-screen displays, HMDs offer several advantages, ultimately leading to increased user task effectiveness as reflected by reduced errors and reduced task completion times (Friend and Grinstead, 1992). The primary disadvantages associated with HMD usage involve physiological and perceptual side effects that often accompany prolonged (e.g., several hours) HMD use.

HMD Advantages. The advantages of HMDs are compactness, low weight, low cost, and rugged characteristics. When used with a portable, wearable computer system, the HMD enables increased user mobility and improve task performance (Friend and Grinstead, 1992). The user can thus directly interact with the environment while simultaneously operating the computer via the HMD (Quill, Kancler, & Masquelier, 1995). In the aircraft maintenance environment, such mobility provides advantages over portable, laptop computer formats, especially during tasks which have a hands-free requirement.

Improved technician performance leads to several benefits (Ebling, 1997; Langford, 1995). For example, reduced maintenance time increases equipment availability. Improvements in task completion times may also enable a reduction in total manpower requirements without over-stressing an already limited maintenance manpower

pool. In general, if the cost to maintain a system can be reduced, possible future budget cuts can be absorbed without sacrificing maintenance effectiveness. As shown by Raaijmakers and Verduyn (1996), technicians with relatively little training can be as effective as experienced technicians when presented with maintenance aids that enable system understanding and comprehensive data presentation for task performance. This may ultimately reduce training requirements and thus reduce the overall cost needed to prepare maintenance technicians.

HMD Disadvantages. The side effects experienced from prolonged HMD use include retinal rivalry, reduced visual field, difficulty with depth perception, and increased eye stress and fatigue (Rash and Martin, 1988; Hale and Piccione, 1990; Haworth and Newman, 1993; Kotulak and Morse, 1995)..

Retinal rivalry involves the reduced ability to selectively switch back and forth between separate images being presented to each eye (Rash and Martin, 1988). This is an important factor related to the use of a monocular HMD where the user must switch between the HMD display in one eye and the working environment in the other. Use of HMDs for periods amounting to a normal maintenance shift may result in adverse effects.

Visual resolution, depth perception, and field of view are all impacted by placing an HMD directly in front of one eye and nothing in front of the other. Adjustable HMDs can be physically aligned to allow the user to see around it (Haworth and Newman, 1993; Kotulak and Morse, 1995). But while adjusting the HMD may improve some effects, it often causes others. Eye strain and fatigue often accompany long-term use of HMDs (Hale and Piccione, 1990). These factors are also often compounded by the effect on the wearer's depth perception associated with HMD use (Hale and Piccione, 1990).

In dynamic environments, such as the flightline, HMD wearers must not only adjust to having a display screen directly in front of one eye, but must also continue to monitor their changing surroundings. Attention must be divided or shifted between external stimuli and the data presented on the HMD screen. As the wearer becomes tired, the eyes are less able to quickly adjust, and performance (and safety) may be compromised (Kotulak and Morse, 1995).

General Dynamics (1991), Masquelier (1991), and Friend and Grinstead (1992) indicated that users did experience a slight degree of eye strain; however, this was attributed to the subjects' unfamiliarity with the wear and use of the HMD. Participants also indicated that they had some interference between the HMD display and objects in the environment on which they were trying to focus. While test participants indicated that they initially had such problems, they also indicated that after becoming accustomed to wearing the HMD, they were able to eliminate these problems.

None of the studies indicated the percentage of participants that experienced these difficulties. The coverage of these issues in each report indicated that the actual problems were minor and applied to few test subjects. However, any indication of such problems should be of potential concern, thus the current research effort also queried the test subjects regarding visual problems during or after participation.

Maintenance Technicians

In their studies, both Masquelier (1991) and Fiend and Grinstead (1992) measured experience level as a between subject's variable. In both studies, technicians were identified as having more experience or less experience as a maintainer. Both studies found that experienced aircraft maintenance technicians statistically took less time and made fewer mistakes than those technicians with limited experience. Thus, the current study was limited to experienced technicians because it was felt that experienced technicians are familiar with the task and can thus focus on a more in-depth analysis of the presentation method and HMD. Inexperienced technicians would likely need to divide attention between the potentially unfamiliar maintenance task and the conditions of the study, ultimately curtailing their ability to provide quality feedback.

Technical Data Presentation

A primary objective of this research was to determine if maintenance technicians' cannon plug pin selection and connection performance can be improved through the use of an *enhanced* technical data presentation method.

Display presentation properties for graphical and scientific data have been extensively studied. Factors such as display background, contrast levels, viewing distance, size, orientation, and amount of irrelevant information on the display have long been identified as areas of concern. When a technician is required to make decisions based on graphically displayed data, these items must be carefully monitored and controlled.

In the current study, textual data was presented in both upper and lower case letters (Helander, 1988). Studies by Bennett and Flach (1992), Boles and Wickens (1987), and Payne and Lang (1995) have shown that mixed-format displays (graphics and text combinations) produce better performance results than either text or graphics alone; therefore, for the current study, all conditions presented both graphics and text.

Wickens, Merwin, and Lin (1994) found that combining 2-D graphics with visual cues (color, bold lettering, highlighting, shading) provides the best performance results. Raaijmakers and Verduyn (1996) found that the performance of Naval engineers was improved during unfamiliar fault detection and identification with a help system that combined graphics with visual cues. Tufte (1997) discusses the advantages of visually "deactivating" the background and minimizing its visual characteristics in relation to items in the foreground. The current study used a combination of these visual enhancements, such as highlighting and shading as visual cues. As part of the highlighting scheme, background information (cannon plug pins *not* to be tested) were grayed out, along with the image of the cannon plug housing.

Galitz (1985) states that, "Specific areas of the screen should be reserved for certain kinds of information, such as commands, error messages, and input fields, and maintain these areas consistently on all screens." Galitz also recommends that for programs that display multiple screens with similar information, the information should be consistently grouped by on-screen location. Furthermore, while the current study focused on providing enhancements to existing digitized paper-based information, only the

information essential to the situation was included (Gordon, 1968; Helander, 1988; Tufte, 1997; Yonas and Pittenger, 1973).

The Present Study

The goal of the present study was to evaluate technician performance while using an HMD on the highly error-prone continuity check task involving cannon plug pin identification.

The present study used a Kopin™ HMD, a monochrome display. The data presented was limited to only the exact information needed to perform the tasks requested in the test program. The Kopin™ HMD also had an adjustable eyepiece that allowed the wearer to set optimal viewing distance, thereby eliminating visual acuity problems associated with viewing displays at improper distances (Giese, 1946; Quill, Kancler, & Batchelor, 1996).

Experienced maintenance technicians were exclusively used for the current study.

Two electronic display conditions were created: a one-to-one representation of the images as seen on the current paper-based technical manuals, and a display format using visual cues and enhancements. Because cannon plugs vary greatly in size and number of pins, a second variable was added to represent "many-pin" and "few-pin" cannon plugs.

Performance was measured in terms of task completion time and correct cannon plug identification. A post-test questionnaire was also administered to collect qualitative information on the technicians' use of the HMD and software systems.

METHOD

Subjects

Avionics maintenance technicians from the 2nd Bomb Wing at Barksdale AFB, LA served as test subjects. The technicians were volunteers chosen from a pool of available personnel. Criteria for consideration were based on time in service, time on the flightline/bench, current duties, and eyesight. Technicians needed a minimum of four years continuous active duty experience, must have been working on the flightline/bench for at least two years, and have been currently performing maintenance duties on the flightline/bench. Technician eyesight, corrected to 20/20, was used as a minimum baseline. While a vision exam was not administered, technicians were verbally queried as to whether they had corrected 20/20 vision.

Ocular dominance (dominant sighting eye) of the technician was not tested, nor was the HMD required to be used on the dominant eye. Experiments indicate that while performing static maintenance tasks, technician performance is not affected by which eye (dominant versus non-dominant) views the HMD (Kancler & Quill, 1997). However, because the findings do suggest that switching the HMD from eye to eye does affect performance, technicians in the current study were discouraged from switching the HMD from eye to eye in the middle of a task.

Hardware and Software

Several hardware components were used in this research. The display device was a commercially available monocular display manufactured by Kopin™. A 486-based laptop computer served as the CPU. The test apparatus comprised a total of five multi-pin cannon plug/breakout box assemblies. A single, rectangular assembly was used for training. The remaining four circular assemblies were used during the experiment.

The software used in the experiment was a locally-developed test program coded in Visual Basic™ 4.0. A menu-driven test program provided the text-based procedures, the accompanying graphical images, and (when appropriate) visual enhancements to the graphical images.

Two individuals were responsible for administering the experiment. The *test administrator* controlled the experiment software via a laptop computer. The *experimenter* was responsible for correct arrangement of the cannon plugs prior to each trial, instruction to the subject, and inspection for subject errors at the end of each trial.

Apparatus

Four different circular cannon plugs were used in the testing phase of this research; each plug contained 12, 13, 55, or 79 "female," (recessed) pins. Female cannon plugs were exclusively chosen to reduce task variance, and because the indexing and visual references are more consistently marked and readable. The four cannon plugs used in the

testing phase were divided into two groups: 'few' pins (12 and 13) and 'many' pins (55 and 79). Figure 1 depicts the front view of the 'few' pin cannon plug layouts and Figure 2 depicts the front view of the 'many' pin cannon plug layouts.

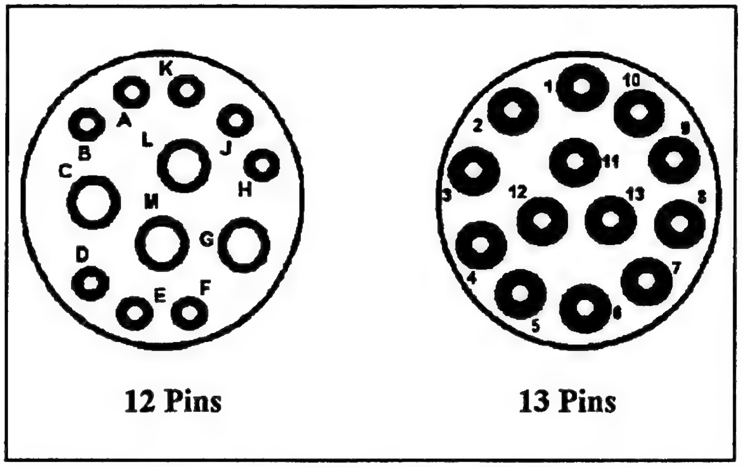

Figure 1: Graphics of Cannon Plug Faces with 'Few' Pins

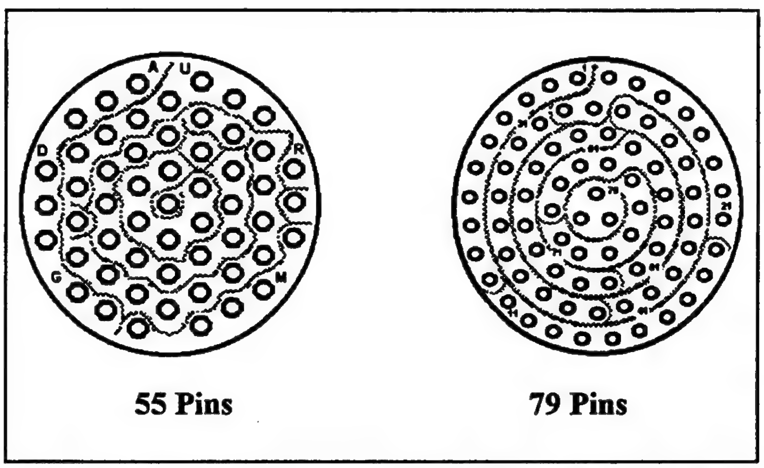

Figure 2: Graphics of Cannon Plug Faces with 'Many' Pins

Each group contained one numerically indexed and one alphabetically indexed cannon plug. While the indexing scheme of the cannon plugs was not tested, the various indexing strategies were selected to be a representative sample of what technicians encounter in the field.

For each trial, subjects were required to locate and identify two specific pins on each cannon plug. Four different pin combinations for each cannon plug were used throughout the test. A random number generator was used to select the first pin combination for each cannon plug. The remaining three combinations were selected based on inter-pin distance and relative location on the cannon plug. This pin selection scheme

was intended to create a set of pin combinations that represented varied distances and orientations.

Two technical data presentation methods were employed: enhanced and unenhanced. Both presentations contained the same basic information that is presented in typical paper technical manuals: a picture of the cannon plug in question, index references, and a table of the appropriate pins to connect. The enhanced presentation contained additional visual cues that highlighted or emphasized the pins to connect while de-emphasizing non-relevant data. Figure 3 contains examples of both presentation methods for the 55 pin cannon plug.

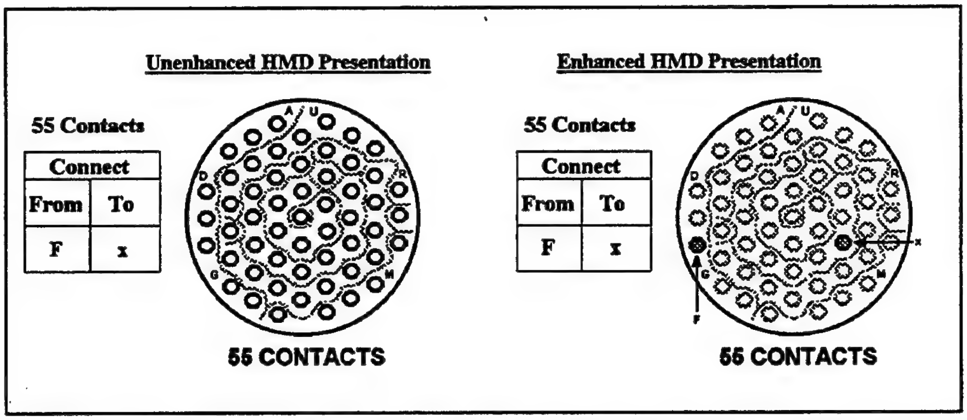

Figure 3: Enhanced and Unenhanced HMD Presentation Methods

Experimental Design

The research methodology was a 2 x 2 within-subjects randomized block design. The independent variables were Pin Number (few [12, 13 pins] vs. many [55, 79 pins]) and Presentation type (enhanced vs. unenhanced). Pin combination (each pair of pins to be tested on the cannon plug) was used as a control variable and not included in the statistical analysis. Subjects received all possible combinations of the four cannon plug sizes and two presentation types, resulting in a total of sixteen trials per subject.

Order of presentation was obtained through a randomized block methodology. This method was selected because the subject pool was not large enough to accommodate a complete counterbalancing of all possible conditions (Keppel & Zedeck, 1989). The block randomization was accomplished as follows:

1) The 16 trials to be performed by each technician were divided into groups of eight, containing two of each cannon plug size (12, 13, 55, and 79 pin) and one of each of the presentation types (enhanced and unenhanced) for each cannon plug pair.
2) Each group of eight trials was then divided in half. Each of the resulting four trials contained one of each of the four cannon plug sizes.
3) Trials were then randomly ordered according to rules one and two above.

Dependent variables were completion time and errors. Task completion time was defined as the time elapsed between the subject's verbal indication of task initiation and task completion. Errors were defined as an incorrect identification of either of the cannon plug pins. Additional qualitative information was also collected in the form of a post-test questionnaire.

Procedure

Subjects were required to complete a personal background form. Subjects then received a briefing on the experimental procedure and training on the use of the HMD. The technicians completed a practice session using a rectangular cannon plug. During the practice session, technicians were exposed to the exact procedures used during the experiment.

Once the subject completed the practice session and indicated an appropriate level of familiarity with the HMD, the experimental session was initiated. Although no time limit was placed on task completion, subjects were asked to work as quickly and as accurately as possible. To provide a common starting point, subjects were allowed to orient the cannon plug and layout the appropriately sized test adapters before each trial began. Subjects were also reminded that the experiment was concerned with task performance and not the operation of the HMD. If a subject was experiencing difficulty in operating the HMD or any of its components, the experimenter provided assistance prior to the beginning of the trial. If the HMD or any of its related components failed during the trial, or the subject was unable to complete the full set of trials for any reason, that subject's data was eliminated from the analysis.

After orienting the cannon plug and locating the adapters, the subject indicated to the program administrator to start the timer. As per the presentation on the HMD, the subject inserted test adapter connectors into the appropriate cannon plug pins. Upon completion, the subject indicated to the program administrator to stop the timer. The experimenter then used a multimeter to check for errors in pin identification. Throughout the experiment, the experimenter recorded any additional observations (technician comments, adjustments made to the HMD) on an experimenter observation form. Following the test, subjects completed the post-test questionnaire.

Hypotheses

The overall research hypothesis was that graphically enhanced data presentations would improve technician cannon plug pin selection and connection task performance. The following hypotheses detail how technician performance was defined:

I. Few-pin cannon plugs will result in faster task completion times than many-pin cannon plugs.
II. The graphically enhanced presentation on the HMD will result in faster task completion times than the unenhanced presentation.
III. In the unenhanced condition, there will be greater task completion times for many-pin cannon plugs than for few-pin cannon plugs. In the enhanced

presentation condition, task completion times will be the same for few- and many-pin cannon plugs.

IV. Few-pin cannon plugs will result in less errors than many-pin cannon plugs.

V. The graphically enhanced presentation on the HMD will result in fewer errors than the unenhanced presentation.

VI. In the unenhanced condition, there will be a greater number of errors for many-pin cannon plugs than for few-pin cannon plugs. In the enhanced presentations condition, errors will be the same for few- and many-pin cannon plugs.

RESULTS

Overview

Twenty-eight aircraft avionics maintenance technicians stationed at Barksdale AFB, LA performed 16 cannon plug pin selection and connection tasks (i.e., 16 trials each). Quantitative and qualitative data were collected from all of the participating test subjects. The results of the quantitative data analysis are presented and discussed in this section. The qualitative data that were collected for all of the 28 participating technicians through the user evaluation questionnaire and the structured interview pertain to the usability of the HMD system and a presentation of information on HMDs. These findings are detailed in the discussion section.

Four of the technician's quantitative data sets were excluded from analysis. One was discarded because the technician was given the wrong cannon plug during two of the tasks. The quantitative data was determined unusable because of the procedural error. A second technician's data was eliminated because the test program sequencing was improperly programmed and the wrong graphical presentations were presented to the technician during the test. Although the technician performed the tasks properly, the incorrect presentation resulted in the experimental design being compromised. The other two data sets were discarded because both of the technicians indicated during the structured interview that they did not see the enhancements on the graphics. Consequently, the data collected for these subjects was incomplete and could not be used.

Dependent Measures.

Data was analyzed using a repeated measures analysis of variance (ANOVA) procedure on SPSS™ 7.5 for Windows 95™. Independent variables were number of pins (few vs. many) and presentation type (unenhanced vs. enhanced). Dependent measures (analyzed separately) were total task time and errors.

Task Time. Results for the task time data analysis are presented in Table 1. Timing began through a verbal cue from the subject, after the subject had selected and oriented the appropriate cannon plug. Timing ended when the subject verbally indicated task completion.

Table 1. ANOVA summary table for task completion times.

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-Value	P-Value
Pin Number	8223.25	1	8223.25	4.280	44.79	<.001
Within	4223.06	23	183.61			
Presentation Type	34941.59	1	34941.59	4.280	92.44	<.001
Within	8693.73	23	377.99			
Number X Type	4995.38	1	4995.38	4.280	39.62	<.001
Within	2900.18	23	126.09			

Cannon Plug Pin Number. The main effect of pin number was significant [$F(1,23)=44.79$, $p<.001$]. Few-pin cannon plugs (those with 12 and 13 pins) yielded shorter task completion times than larger cannon plugs (those with 55 and 79 pins).

Presentation Type. The main effect of presentation type was also significant [$F(1,23)=92.44$, $p<.001$]. As hypothesized, the enhanced display format yielded shorter task completion times than the unenhanced display format.

Pin Number X Presentation Type. As hypothesized, the interaction of pin number X presentation type was significant [$F(1,23)=39.62$, $p<.001$]. In the unenhanced presentation condition, many-pin plugs were associated with significantly greater task completion times than few-pin plugs. In the enhanced presentation condition, no statistically significant difference in task completion times was observed between few- and many-pin cannon plugs (Figure 4).

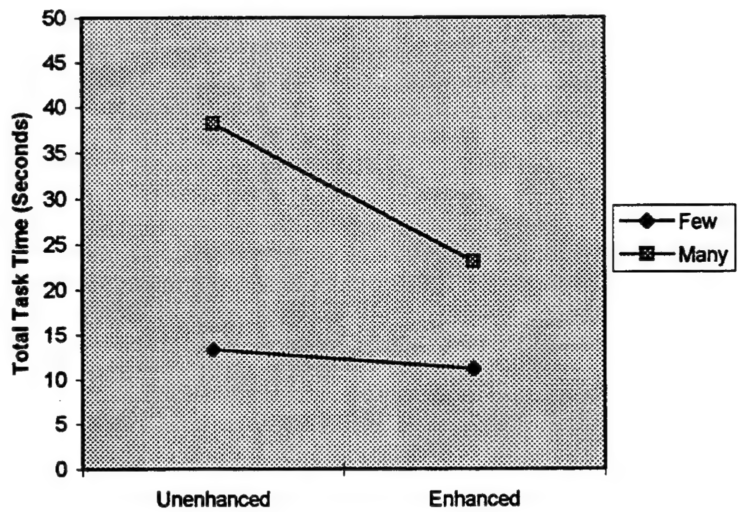

Figure 4. The interaction of pin number X presentation type on total task time in seconds.

Error Rate. Results for the error data analysis are presented in Table 2. Error rate was calculated based on the technician's ability to correctly identify the proper pins the first time. Technicians were allowed only one attempt per trial. To control for data collection variance, the same experimenter conducted all the data collection activities.

Table 2. ANOVA summary table for errors.

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-Value	P-Value
Pin Number	.128	1	.128	4.280	1.205	.284
Within	2.435	23	.11			
Presentation Type	3.19	1	3.19	4.280	20.255	<.001
Within	3.62	23	.16			
Number X Type	2.19	1	2.19	4.280	23.73	<.001
Within	2.12	23	.09			

Cannon Plug Pin Number. The main effect of pin number was not significant [F(1,23)=1.205, p>.05]. Contrary to hypothesis, few-pin cannon plugs (those with 12 and 13 pins) did not yield fewer errors than many-pin cannon plugs.

Presentation Type. The main effect of presentation type was significant [F(1,23)=20.255, p<.001]. As hypothesized, the enhanced display format yielded fewer errors than the unenhanced display format.

Pin Number X Presentation Type. As hypothesized, the interaction of plug size X presentation type was significant [F(1,23)=39.62, p<.001]. In the unenhanced presentation condition, many-pin plugs were associated with a statistically significant greater error rate than few-pin plugs. In the enhanced presentation condition, no statistically significant difference in error rate was observed between few- and many-pin cannon plugs (Figure 5).

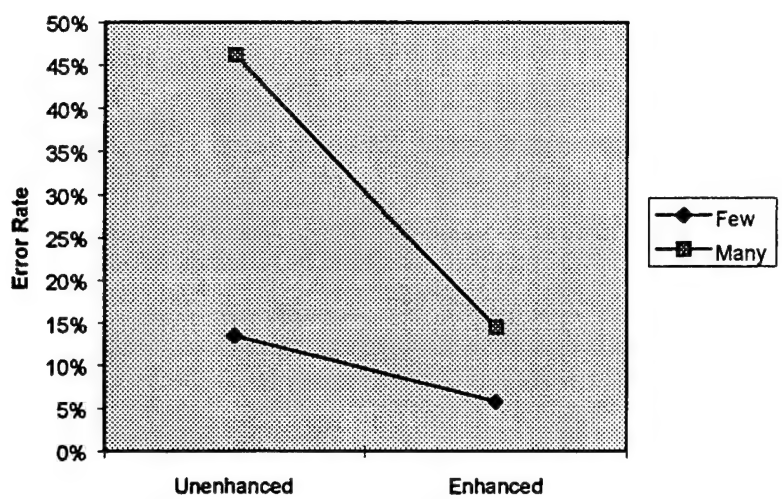

Figure 5. The interaction of pin number X presentation type on task error rate.

DISCUSSION

Quantitative Results

Task Time. The overall mean task completion time data collected for this thesis supports the hypotheses that the enhanced data presentation enabled technicians to better complete the experimental task.

Pin Number. For task time, the significant main effect of pin number was likely due to several factors, the most notable being the dramatic difference in the actual number of pins. The second factor is the combination of the cannon plug pin size and cannon plug assembly size. For few-pin cannon plugs, the average plug assembly size was slightly smaller than the many-pin cannon plugs; however, for the few-pin cannon plugs, average pin size was *greater* than the many-pinned cannon plugs. Also, for the many-pin cannon plugs, pin density (number of pins per area) was certainly higher. In terms of target detection, for the few-pin plugs the ratio of target area (size of specified pins) to non-target area (the remaining pins plus the area of the cannon plug face) was 1 to 20. For the larger plugs, this ratio was 1 to 60. This disparity in "target-to-noise" ratio may have contributed to the overall effect of cannon plug size on task completion times.

Presentation Type. For task time, the significant main effect of presentation type is consistent with the notion that visual cues such as highlighting will assist in target detection. Furthermore, the enhancement scheme called for the de-highlighting (graying out) of non-target pins. As per Wickens, Merwin, and Lin (1994), Raaijmakers and Verduyn (1996), and Tufte (1997), the combination of these strategies produce the expected result of reduced target detection times.

Pin Number X Presentation Type. The significant interaction of pin number X presentation type indicates that the many-pin plugs benefit more from the enhanced display condition. It is possible that the smaller plug sizes yielded a "floor effect," while the many-pin plugs approached worst case. The present study did not include several cannon plug formats. Future research may address cannon plugs with intermediate numbers of pins to establish a potential "critical limit" at which graphical enhancements significantly improve performance.

Error Rate. Similar to task times, overall task error data collected for this thesis supports the hypotheses that the enhanced data presentation enabled technicians to better complete the experimental task.

Pin Number. The non-significant finding of this main effect may have been due to a possible speed/accuracy tradeoff. Subjects were told to work as quickly and accurately as possible; however, quicker completion times may have been sacrificed for higher accuracy, especially in the many-pin cannon plug conditions. This scenario, when coupled with a potential few-pin "floor effect," may have led to this non-significant finding.

Presentation Type. As with task time, the significant main effect of presentation type on errors was consistent with the findings of Wickens, Merwin, and Lin (1994) and

Raaijmakers and Verduyn (1996) indicating graphical enhancements yield improved performance.

Pin Number X Presentation Type. The significant interaction of pin number X presentation type follows a pattern similar to the task time results: the many-pin plug sizes benefit more from the enhanced display condition. Again, it is possible that the smaller plug sizes yielded a "floor effect," while the larger plug sizes approached worst case. The conclusion to be drawn from the time and error data can only be interpreted to the extent that enhancements to 12- and 13-pin connector graphics do not lead to improved performance, while enhancements to 55- and 79-pin connector graphics do.

Qualitative Results

Data in the form of a questionnaire and interview were collected from all 28 of the test participants. Most of the data was directed at the usability the information presented on the HMD and comfort of use of the HMD.

Information Presented on the HMD. The technicians were asked if the information presented on the HMD was readable and if and when they noticed a difference in presentation types (unenhanced vs. enhanced). All 28 technicians indicated that the information itself was mostly legible. Some references, such as numbers and the extreme corners of the HMD were said to be "fuzzy;" but, all indicated that the HMD was adequate in presenting the data.

Some technicians indicated apprehensiveness about relying on the enhanced presentations. The reasons given were lack of trust in the presentation, the plugs were easy to read, and they felt more comfortable (and familiar with) counting the pins out. The technicians indicated that the pin counting and mistrust of presentation were the result of encountering numerous technical orders that were improperly marked and that they did not inherently trust technical data.

HMD Use. The technicians in this study only wore the HMD system for approximately 30 minutes. The tasks were performed in a static environment with few outside distractions or interference. Even so, the technicians provided insightful comments about the HMD and its potential role in the flightline maintenance environment.

Technicians were asked about the HMD and their ability to use it with their current job requirements. The primary concerns expressed by the technicians were potential eye strain caused by switching focus between the cannon plug and HMD. Additionally, several extra clips and accessories that were part of the HMD assembly interfered with the HMD use (an earpiece and microphone were not used). Finally, the weight of the system was seen as a potential cause of headaches and sweating, resulting in the HMD slipping down on the forehead.

Even with these concerns, the technicians overwhelmingly indicated that the HMD would be an asset to them in performing their daily duties. Twenty-three of the technicians said the HMD could be used in troubleshooting, schematic tracing, or tasks that required their hands to be free. Other suggested uses were in dark, tight places,

during night-time operations, and on tasks that required two people to perform. The suggestion was that technicians could be electronically connected to the same reference and could work together better by using the HMD.

Technicians felt that having wiring diagrams, schematics, and checklists on an HMD would enable technicians to concentrate on the task and not the data needed to perform the task. As one technician put it, some tasks require one hand to hold a flashlight, one hand to hold the test leads, one hand to hold the screwdriver, one hand to operate the test equipment, and one hand to turn the page in the TO -- "even an octopus would be hard pressed" to do the task properly.

Other suggestions included hooking the HMD up to an on-line system that would enable the wearer to access any and all the information needed for the job. Suggested information included supply information, core automated maintenance system data, all the aircraft maintenance history, the World Wide Web, and e-mail. Incorporating the HMD into a complete system of miner's light, ear defenders, radio, and, inter-phone was also frequently mentioned.

CONCLUSIONS AND RECOMMENDATIONS

The results of this research suggest that enhanced cannon plug pin selection task data presented on an HMD would be useful in improving maintenance technician performance. Technicians completed the cannon plug pin selection and connection tasks quicker and committed fewer errors when they used the enhanced data presentation to perform the task while wearing the HMD. Analysis of the obtained data revealed statistically significant results that indicated that the enhanced data presentation method did reduce the task performance time and error rate. Such performance improvements could ultimately lead to reduced maintenance costs. Improved technician performance can lead to benefits such as increases equipment availability, reduction in total manpower requirements, and reduced costs associated with logistics requirements.

Qualitative data obtained from technician feedback also suggest that HMD systems would be advantageous for and used by technicians in the performance of their maintenance duties. Technicians reported that they encountered very few problems using the HMD and would like to see some type of HMD system available for their use.

Future Research

Future research should incorporate a wider variety of cannon plug formats, including higher varieties of pin numbers, plug shapes, and indexing schemes. For example, the cannon plugs in the present study were selected to represent the extreme cases of pin numbers (few and many). Results from the current study showed differences in technician performance between many- and few-pin cannon plugs for unenhanced presentations, while there were no differences for the enhanced presentations. Future research could set up intermediate pin sizes and establish at what pin number graphical enhancements significantly improve performance. Additional graphical enhancement strategies could also be investigated, such as color coding or flashing indicators.

The portability of the current HMD system was not tested to its fullest extent in the present study. Subjects did not have to move around to perform the required maintenance tasks. Future research should investigate flightline maintenance tasks and other tasks requiring increased mobility using enhanced presentations. As possible future avenues of study, the technicians in the present study suggested system troubleshooting tasks, inspection tasks, schematic and troubleshooting chart reading tasks, and tasks that required coordinated teams of technicians operating concurrently.

The results of the present study indicated that improved task information presentation methods can improve technician performance, ultimately resulting in reduced maintenance costs and increased equipment availability. While the current study uncovered methodologies that will reduce errors, these methodologies did not completely eliminate errors. Furthermore, a cost-effective strategy must be developed to integrate these methodologies into present and future digitization efforts. For these reasons, further research in the presentation of task information and cannon plug design should be

pursued, with the ultimate goals of task time improvement, error reduction, and, ultimately, maintenance cost reduction.

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